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(54) **METHOD OF FABRICATING PIEZOELECTRIC MATERIAL WITH SELECTED C-AXIS ORIENTATION**

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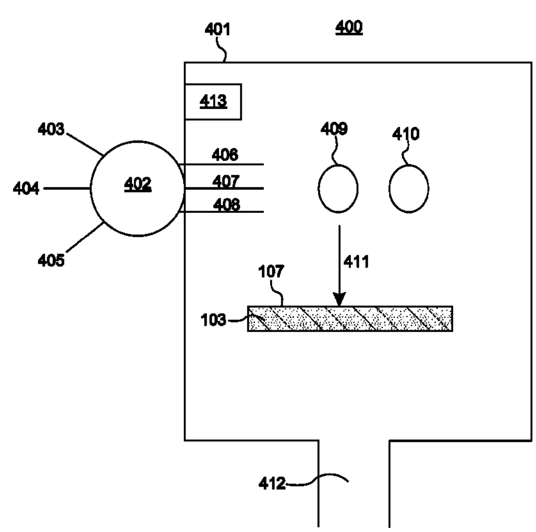
(57) **ABSTRACT**

In accordance with a representative embodiment, a method of fabricating a piezoelectric material comprising a first component and a second component comprises: providing a substrate; flowing hydrogen over the substrate; flowing the first component to form the piezoelectric material over a target; and sputtering the piezoelectric material from the target on the substrate. In accordance with another representative embodiment, a method of fabricating a bulk acoustic wave (BAW) resonator comprises: forming a first electrode over a substrate; forming a seed layer over the substrate; and depositing a piezoelectric material having a compression-negative (C_N) polarity. The depositing of the piezoelectric material comprises: flowing a first component of the piezoelectric material to form the piezoelectric material over a target comprising a second component of the piezoelectric material; and sputtering the piezoelectric material from the target to the substrate.

23 Claims, 10 Drawing Sheets



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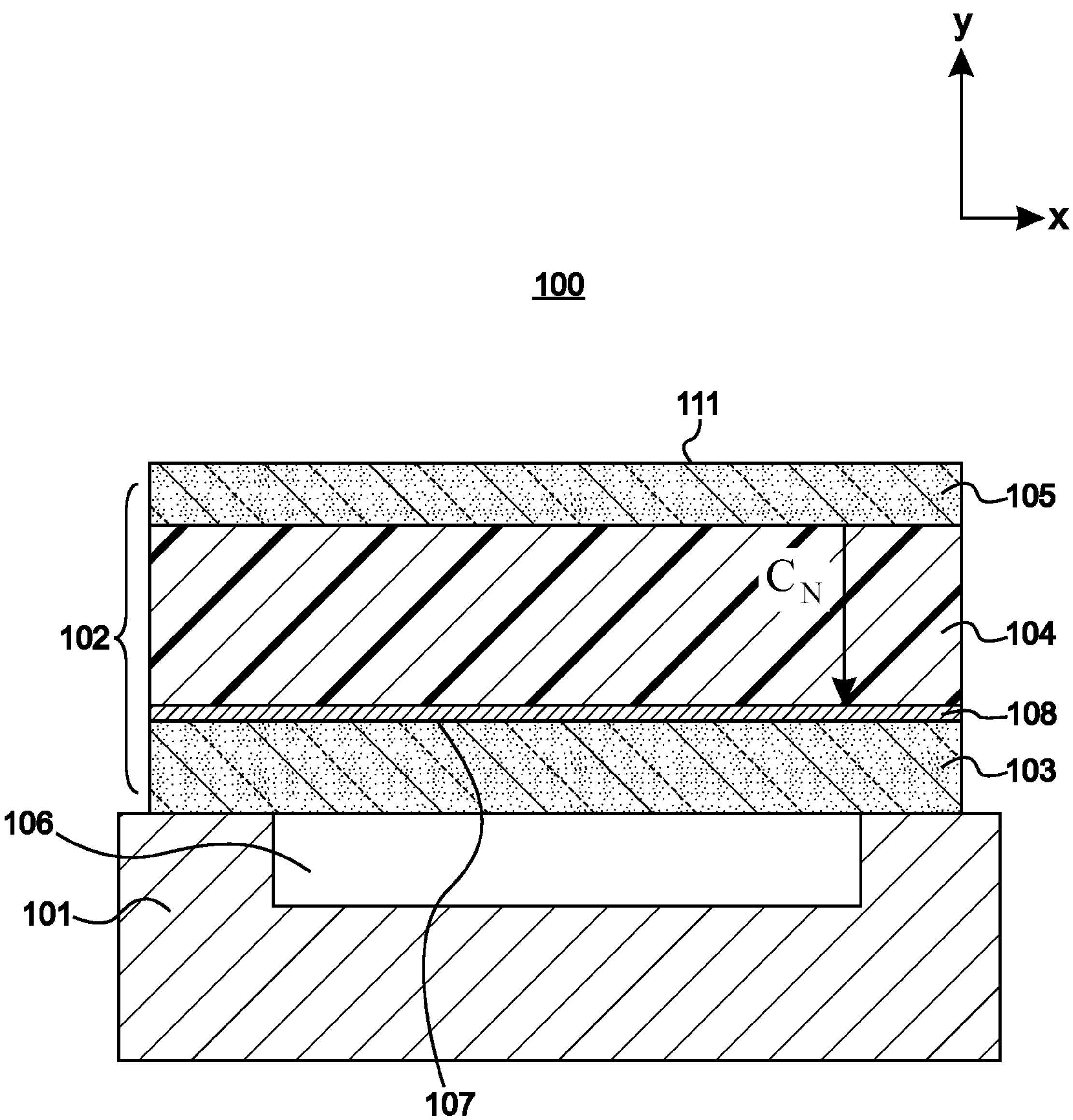

FIG. 1A

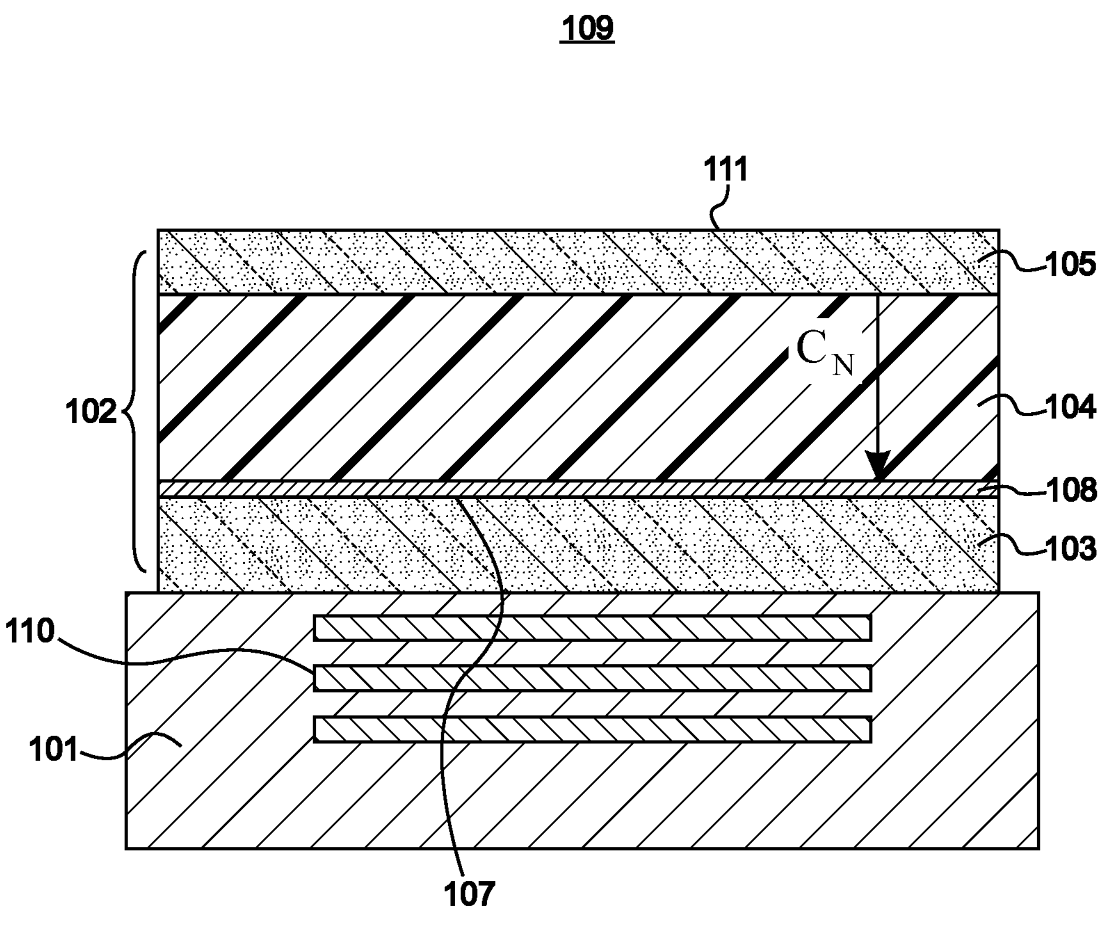

FIG. 1B

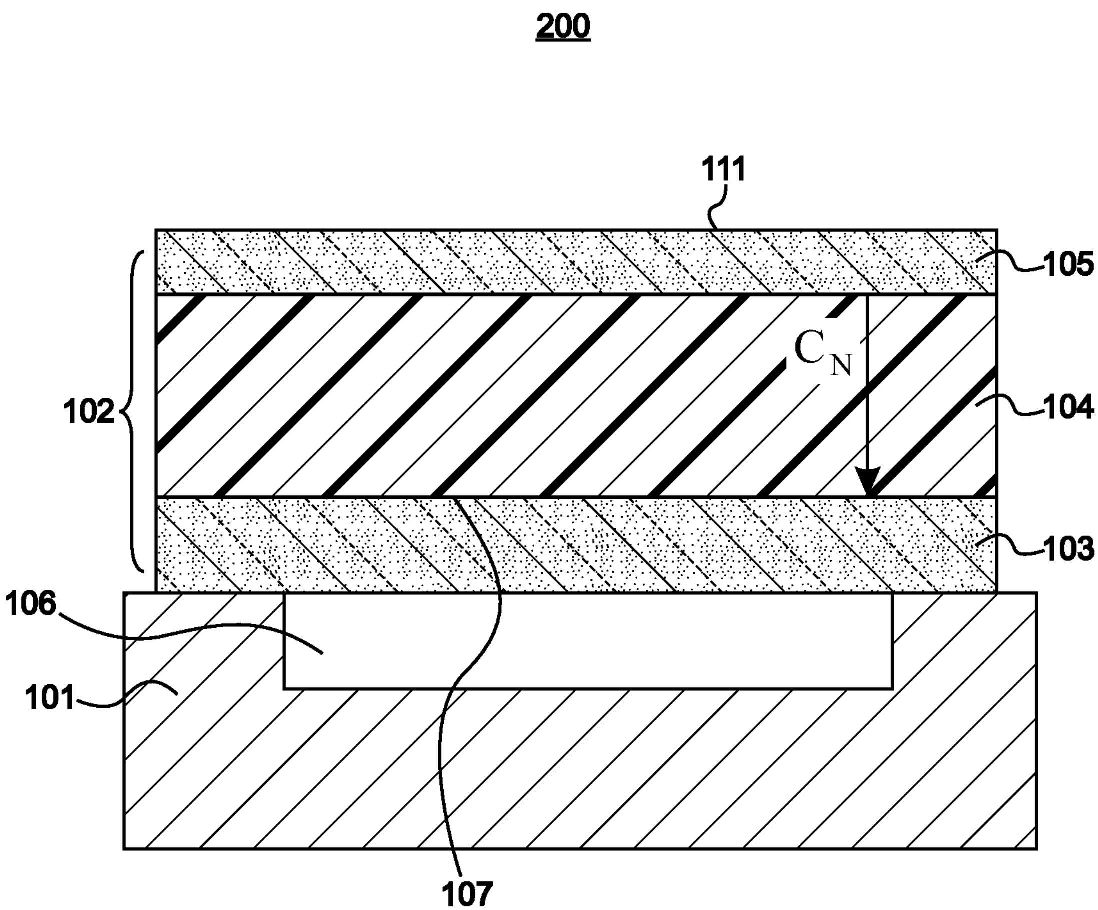

FIG. 2A

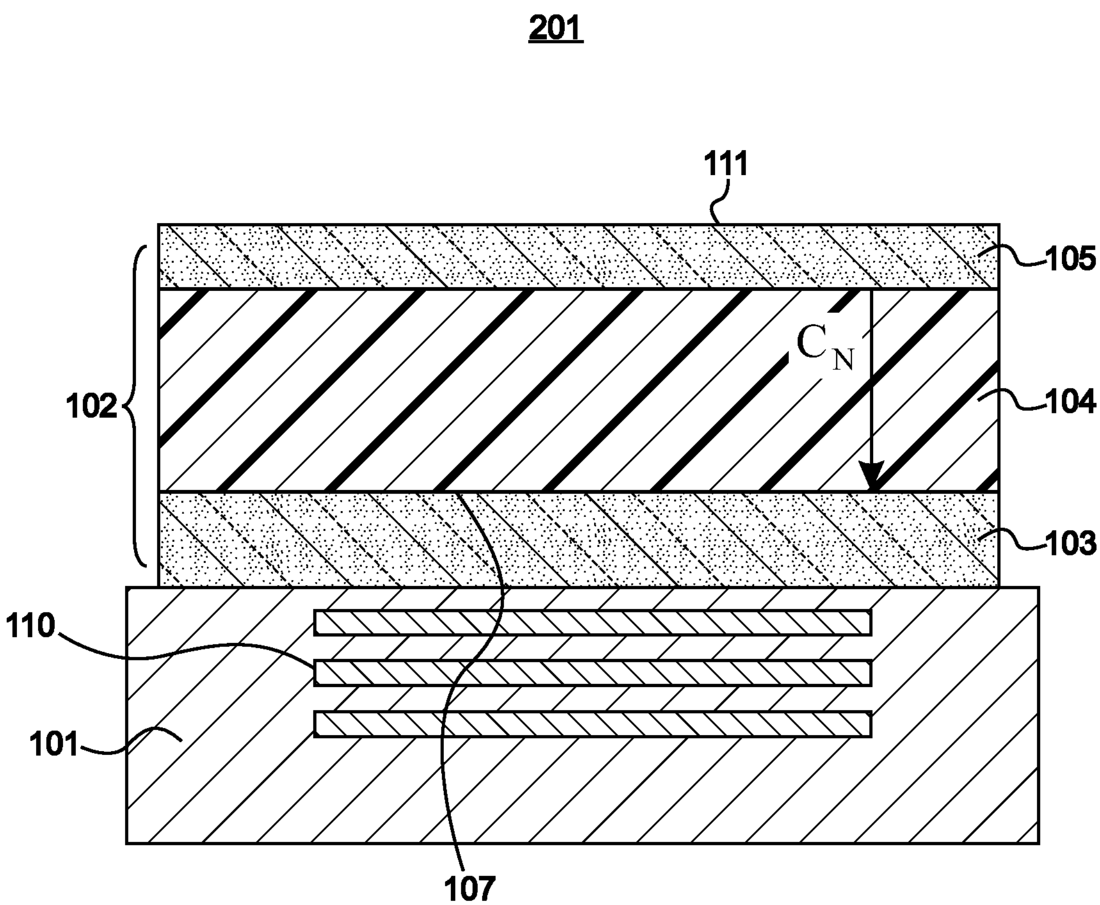

FIG. 2B

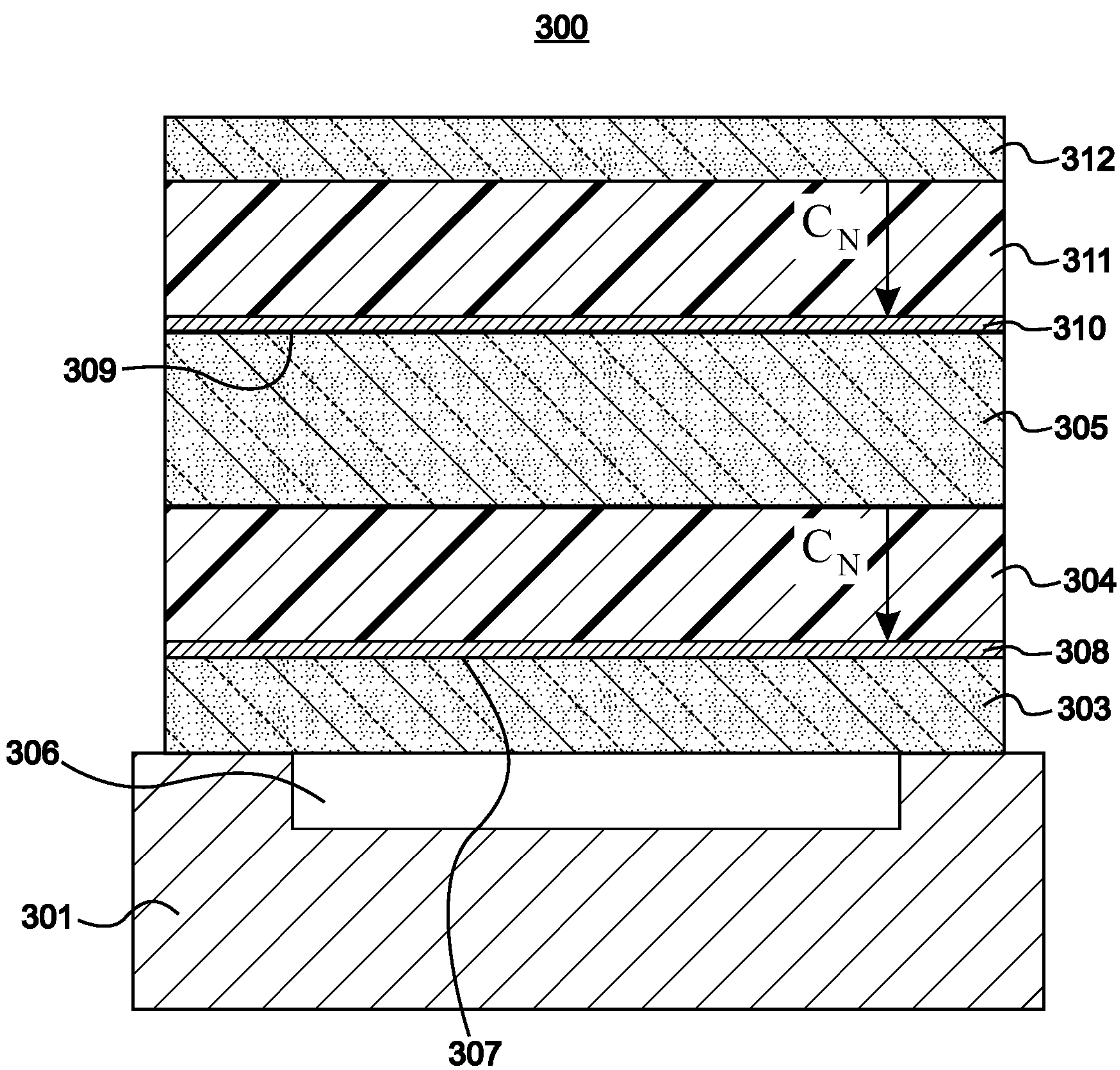

FIG. 3A

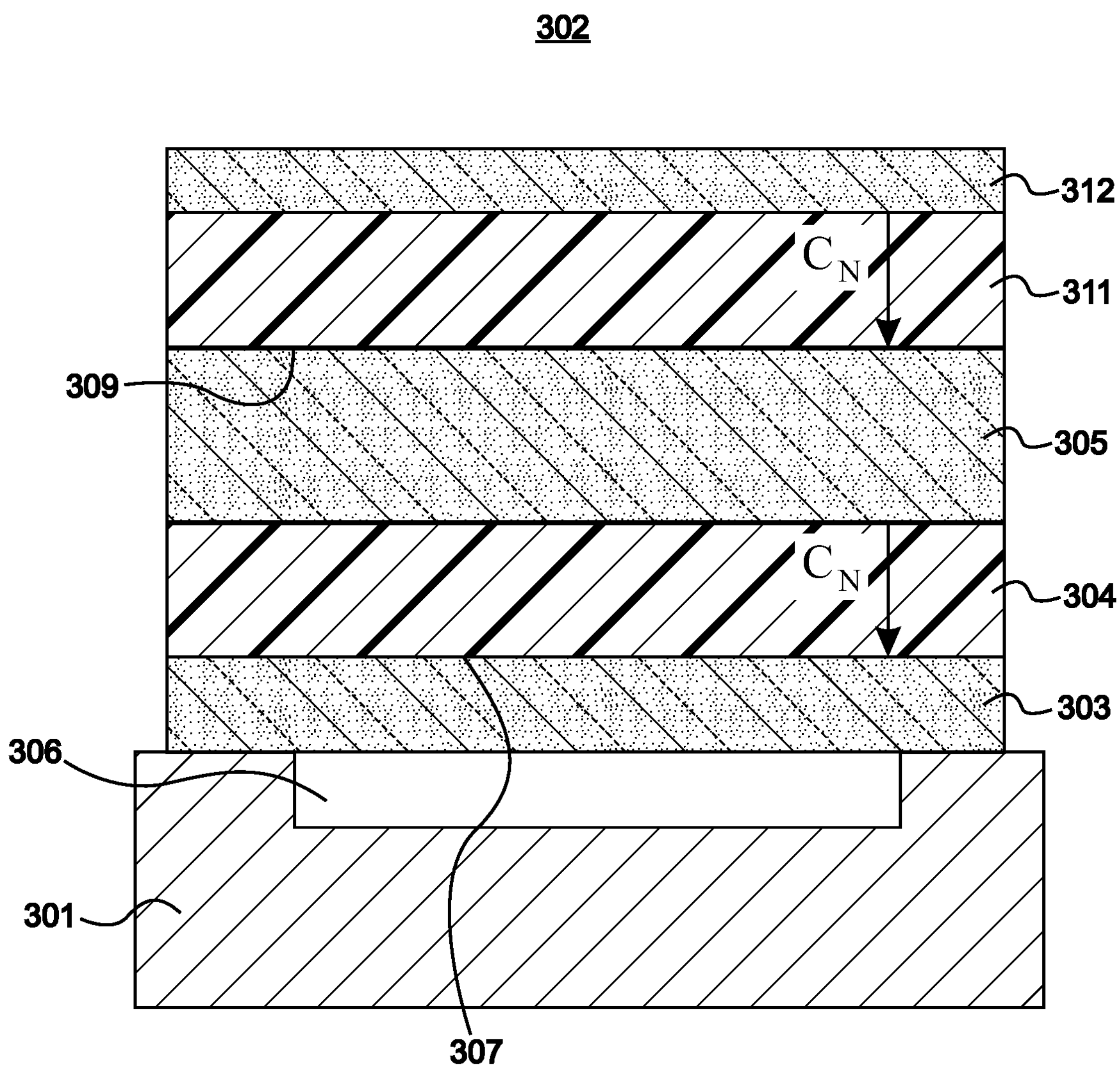

FIG. 3B

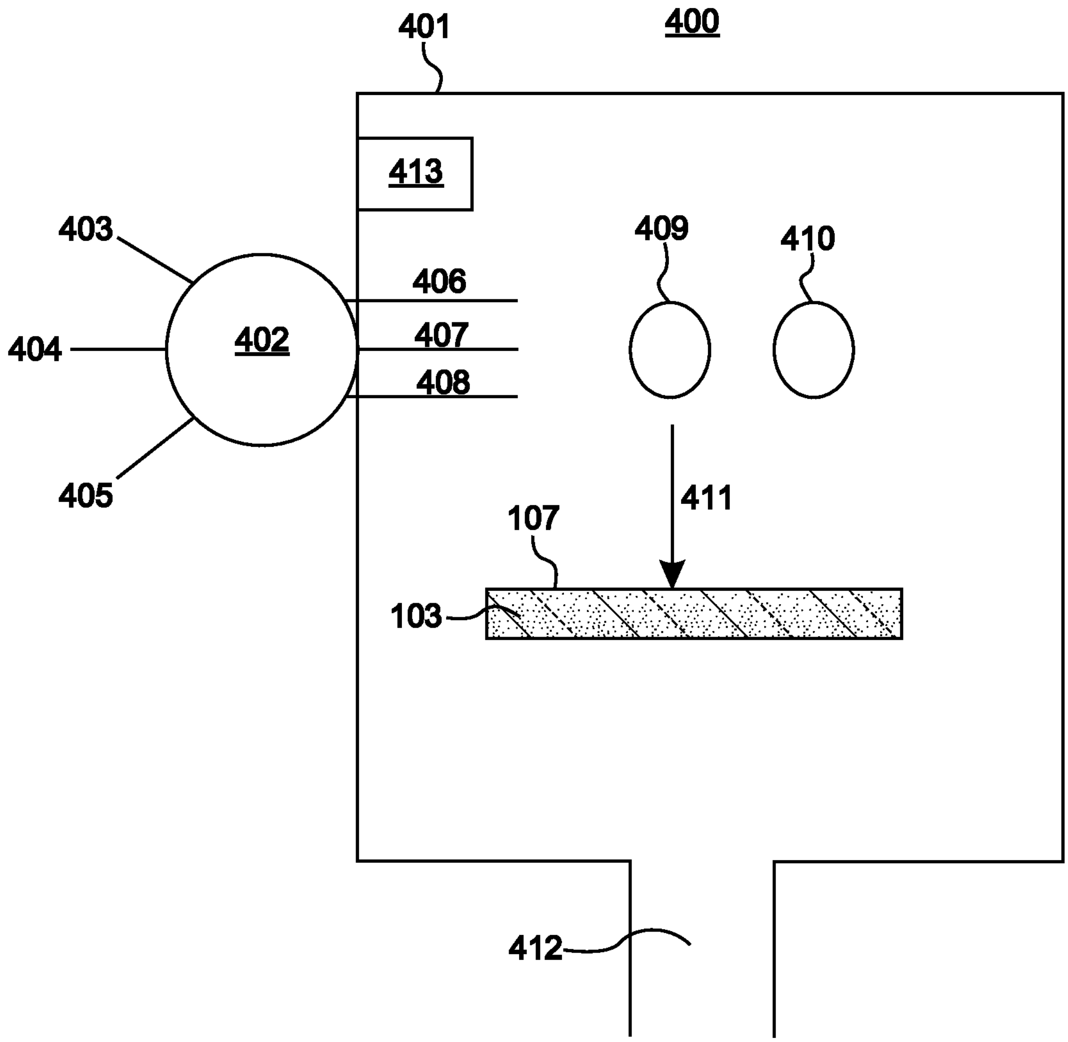

FIG. 4

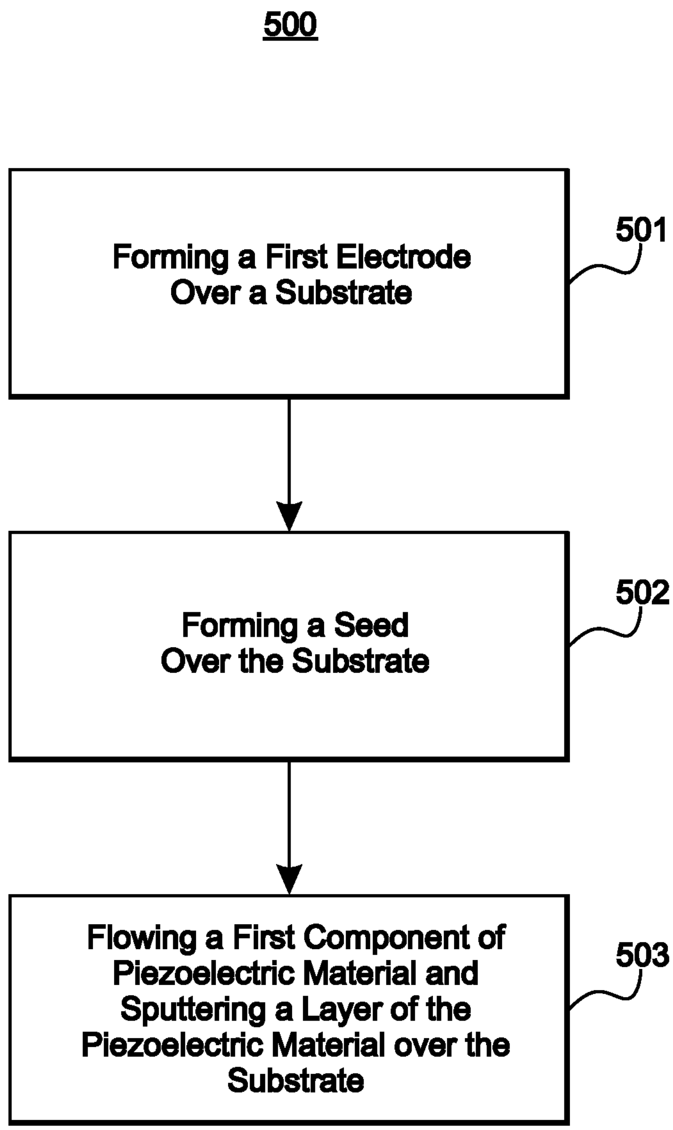
500
Forming a First Electrode Over a Substrate
501
Forming a Seed Over the Substrate
502
Flowing a First Component of Piezoelectric Material and Sputtering a Layer of the Piezoelectric Material over the Substrate
503

FIG. 5

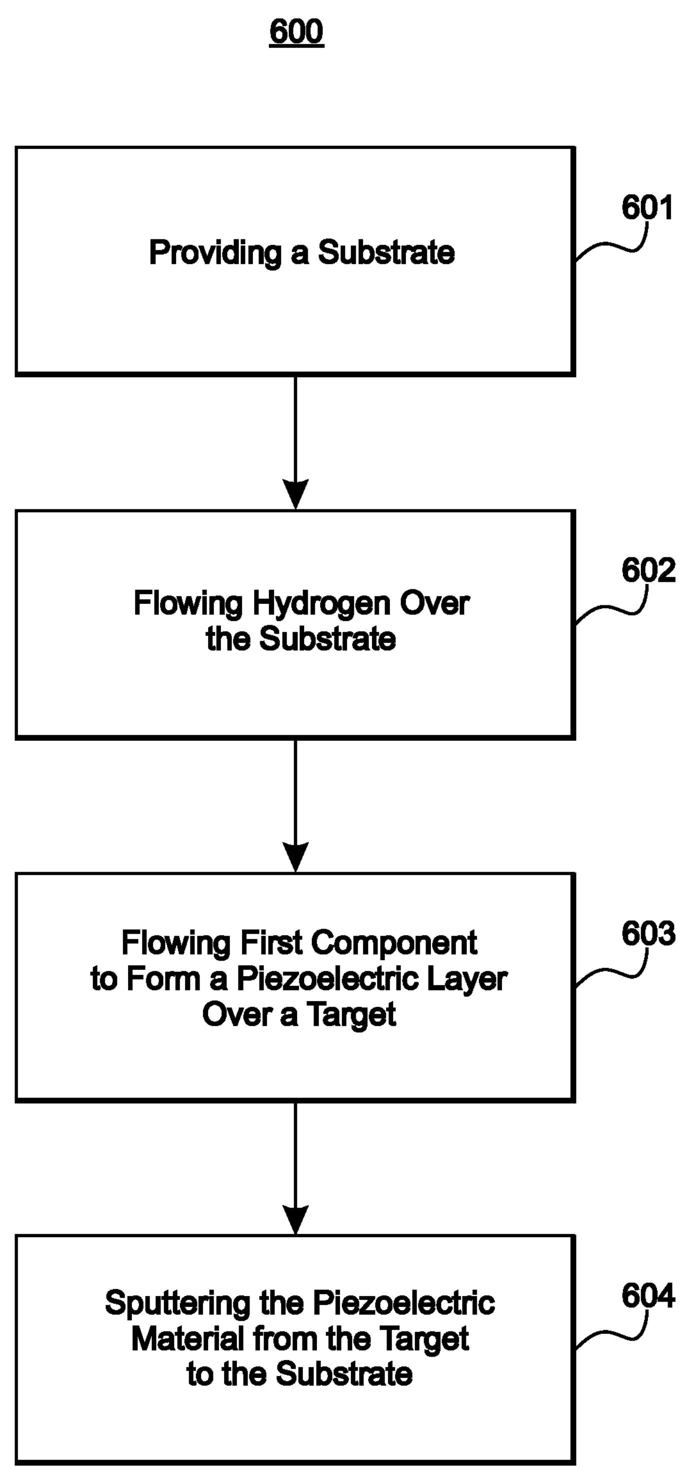
600
Providing a Substrate
601
Flowing Hydrogen Over the Substrate
602
Flowing First Component to Form a Piezoelectric Layer Over a Target
603
Sputtering the Piezoelectric Material from the Target to the Substrate
604

FIG. 6

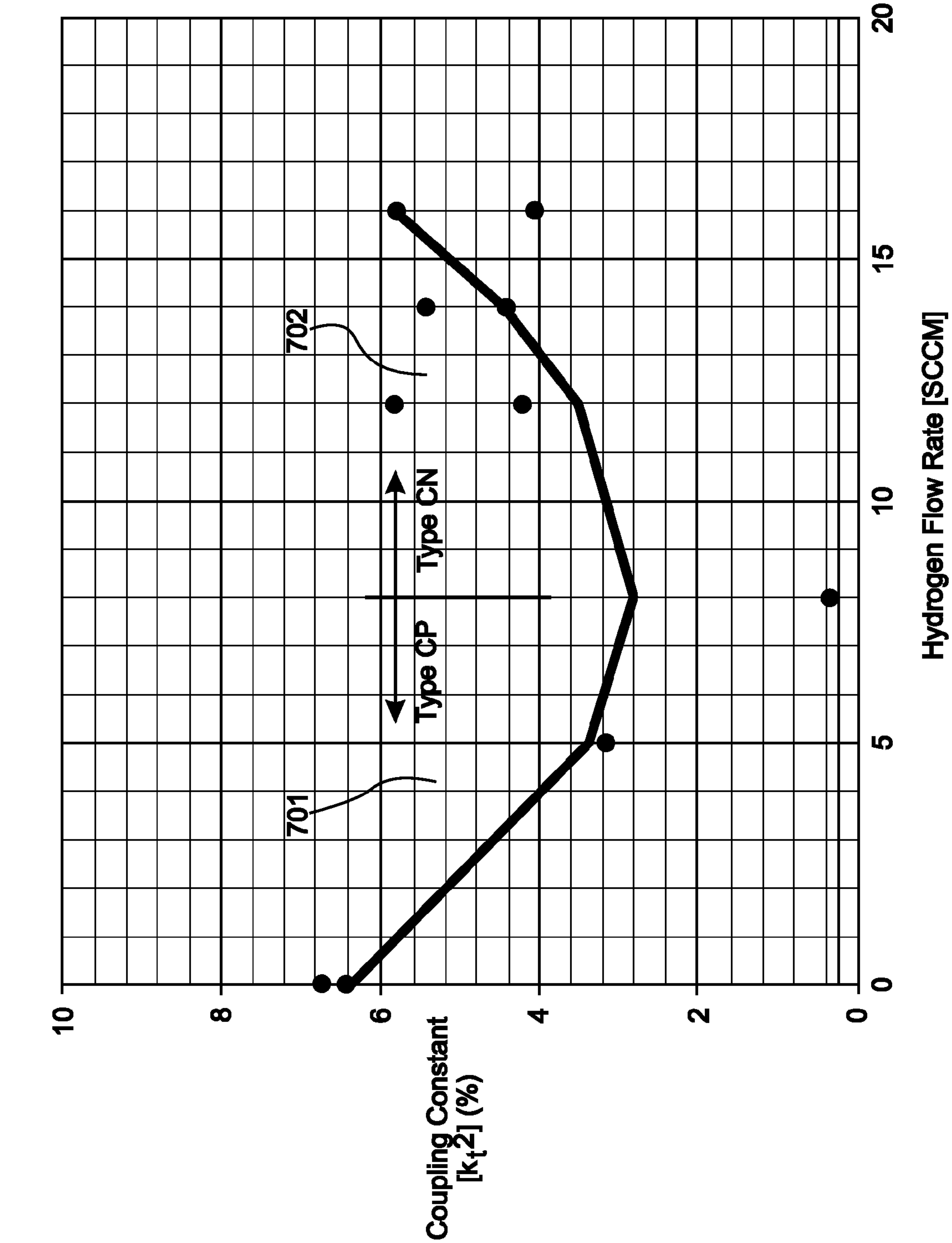
Coupling Constant
[k_t^2] (%)
10
8
6
4
2
0
0
5
10
15
20
Hydrogen Flow Rate [SCCM]
Type CP
Type CN
701
702

FIG. 7

METHOD OF FABRICATING PIEZOELECTRIC MATERIAL WITH SELECTED C-AXIS ORIENTATION

BACKGROUND

In many electronic applications, electrical resonators are used. For example, in many wireless communications devices, radio frequency (RF) and microwave frequency resonators are used as filters to improve reception and transmission of signals. Filters typically include inductors and capacitors, and more recently resonators.

As will be appreciated, it is desirable to reduce the size of components of electronic devices. Many known filter technologies present a barrier to overall system miniaturization. With the need to reduce component size, a class of resonators based on the piezoelectric effect has emerged. In piezoelectric-based resonators, acoustic resonant modes are generated in the piezoelectric material. These acoustic waves are converted into electrical waves for use in electrical applications.

One type of piezoelectric resonator is a Bulk Acoustic Wave (BAW) resonator. The BAW resonator includes an acoustic stack comprising, inter alia, a layer of piezoelectric material disposed between two electrodes. Acoustic waves achieve resonance across the acoustic stack, with the resonant frequency of the waves being determined by the materials in the acoustic stack. One type of BAW resonator comprises a piezoelectric film for the piezoelectric material. These resonators are often referred to as Film Bulk Acoustic Resonators (FBAR).

FBARs are similar in principle to bulk acoustic resonators such as quartz, but are scaled down to resonate at GHz frequencies. Because the FBARs have thicknesses on the order of microns and length and width dimensions of hundreds of microns. FBARs beneficially provide a comparatively compact alternative to certain known resonators.

FBARs may comprise a membrane (also referred to as the acoustic stack) disposed over air. Often, such a structure comprises the membrane suspended over a cavity provided in a substrate over which the membrane is suspended. Other FBARs may comprise the membrane formed over an acoustic mirror formed in the substrate. Regardless of whether the membrane is formed over air or over an acoustic mirror, the membrane comprises a piezoelectric layer disposed over a first electrode, and a second electrode disposed over the piezoelectric layer.

The piezoelectric layer comprises a crystalline structure and a polarization axis. Piezoelectric materials either compress or expand upon application of a voltage. By convention, a piezoelectric material that compresses when a voltage of a certain polarity is applied is referred to as compression-positive (C_P) material, whereas a piezoelectric material that expands upon application of the voltage is referred to as a compression-negative (C_N) material. The polarization axis of C_P piezoelectric materials is antiparallel to the polarization axis C_N material.

An FBAR is a polarity-dependent device as a result of polarity dependence of the piezoelectric material that constitutes part of the FBAR. A voltage of a given polarity applied between the electrodes of the FBAR will cause the thickness of the FBAR to change in a first direction, whereas the same voltage of the opposite polarity will cause the thickness of the FBAR to change in a second direction, opposite the first direction. (The thickness of the FBAR is the dimension of the FBAR between the electrodes.) For example, a voltage of the given polarity will cause the thickness of the FBAR to increase whereas a voltage of the opposite polarity will cause

the FBAR to decrease. Similarly, a mechanical stress applied to the FBAR that causes the thickness of the FBAR to change in a first direction will generate a voltage of the given polarity between the electrodes of the FBAR, whereas a mechanical stress that causes the thickness of the FBAR to change in a second direction, opposite the first direction, will generate a voltage of the opposite polarity between the electrodes of the FBAR. As such, a mechanical stress applied to the FBAR that causes the thickness of the FBAR to increase will generate a voltage of the given polarity, whereas a mechanical stress that causes the thickness of the FBAR to decrease will generate a voltage of the opposite polarity.

The piezoelectric layer of an FBAR is often grown over a first electrode and beneath a second electrode. The orientation of the C-axis can be governed by the first layer formed over the first electrode. For example, in growing aluminum nitride (AlN) with a C_P film orientation, the formation of a native oxide layer over the first electrode (e.g., Mo) is believed to cause the first layer of the piezoelectric crystal to be Al. Ultimately, the crystalline orientation of the AlN formed results in piezoelectric film's having C_P orientation and its attendant properties. Growth of C_N piezoelectric layers (e.g., AlN) by known methods has proven to be more difficult. It is believed that nitrogen and oxygen may be adsorbed at the surface of the first electrode, with the forming of a layer of Al over this adsorbed material. As such, rather than forming the desired C_N piezoelectric layer, C_P piezoelectric material is formed.

In certain applications, it is desirable to be able to select the orientation of the piezoelectric material, and to fabricate both C_P piezoelectric material and C_N piezoelectric material on the same structure. For example, in certain applications it is useful to provide a single-ended input to a differential output. One known resonator structure having a differential output comprises coupled mode resonators. Filters based on coupled mode acoustic resonators are often referred to as coupled resonator filters (CRFs). CRFs have been investigated and implemented to provide improved passband and isolation of the transmit band and receive band of duplexers, for example. One topology for CRFs comprises an upper FBAR and a lower FBAR. The two electrodes of one of the FBARs comprise the differential outputs, and one of the inputs to the lower resonator provides the single-ended input. The second electrode provides the ground for the device. However, while the stacked-FBAR CRF shows promise from the perspective of improved performance and reduced area or footprint due to its vertical nature, in order to attain this structure, the orientation of the compression axes (C-axes) of individual piezoelectric materials must be tailored to the application. For example, it may be useful to have one piezoelectric layer with its C-axis (e.g., C_N) in one direction, and the second piezoelectric layer to have its crystalline orientation anti-parallel (e.g., C_P) to the C-axis of the first piezoelectric layer. Unfortunately, and as alluded to above, using known methods of fabricating piezoelectric layers, it is difficult to select the orientation of the piezoelectric crystal during fabrication, and especially on the same wafer.

What is needed, therefore, is a method of fabricating piezoelectric materials that overcomes at least the known shortcomings described above.

SUMMARY

In accordance with a representative embodiment, a method of fabricating a piezoelectric material comprising a first component and a second component comprises: providing a substrate; flowing hydrogen over the substrate; flowing the first component to form the piezoelectric material over a target; and sputtering the piezoelectric material from the target on the substrate.

In accordance with another representative embodiment, a method of fabricating a bulk acoustic wave (BAW) resonator comprises: forming a first electrode over a substrate; forming a seed layer over the substrate; depositing a piezoelectric material having a compression-negative (C_N) polarity, the depositing comprising: flowing a first component of the piezoelectric material to form the piezoelectric material over a target comprising a second component of the piezoelectric material; and sputtering the piezoelectric material from the target to the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

The illustrative embodiments are best understood from the following detailed description when read with the accompanying drawing figures. It is emphasized that the various features are not necessarily drawn to scale. In fact, the dimensions may be arbitrarily increased or decreased for clarity of discussion. Wherever applicable and practical, like reference numerals refer to like elements.

FIG. **1**A shows a bulk acoustic wave (BAW) resonator fabricated in accordance with a representative embodiment.

FIG. **1**B shows a BAW resonator fabricated in accordance with a representative embodiment.

FIG. **2**A shows a BAW resonator fabricated in accordance with a representative embodiment.

FIG. **2**B shows a BAW resonator fabricated in accordance with a representative embodiment.

FIG. **3**A shows a BAW resonator fabricated in accordance with a representative embodiment.

FIG. **3**B shows a BAW resonator fabricated in accordance with a representative embodiment.

FIG. **4** shows a simplified schematic diagram of a deposition system in accordance with a representative embodiment.

FIG. **5** shows a flow-chart of a method of fabricating a piezoelectric layer in accordance with a first representative embodiment.

FIG. **6** shows a flow-chart of a method of fabricating a piezoelectric layer in accordance with a second representative embodiment.

FIG. **7** shows a graph of the coupling coefficient versus hydrogen flow rate during the forming of a piezoelectric layer.

DEFINED TERMINOLOGY

It is to be understood that the terminology used herein is for purposes of describing particular embodiments only, and is not intended to be limiting. The defined terms are in addition to the technical and scientific meanings of the defined terms as commonly understood and accepted in the technical field of the present teachings.

As used in the specification and appended claims, the terms ‘a’, ‘an’ and ‘the’ include both singular and plural referents, unless the context clearly dictates otherwise. Thus, for example, ‘a device’ includes one device and plural devices.

As used in the specification and appended claims, and in addition to their ordinary meanings, the terms ‘substantial’ or ‘substantially’ mean to with acceptable limits or degree. For example, ‘substantially cancelled’ means that one skilled in the art would consider the cancellation to be acceptable.

As used in the specification and the appended claims and in addition to its ordinary meaning, the term ‘approximately’ means to within an acceptable limit or amount to one having ordinary skill in the art. For example, ‘approximately the same’ means that one of ordinary skill in the art would consider the items being compared to be the same.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation and not limitation, specific details are set forth in order to provide a thorough understanding of illustrative embodiments according to the present teachings. However, it will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure that other embodiments according to the present teachings that depart from the specific details disclosed herein remain within the scope of the appended claims. Moreover, descriptions of well-known apparati and methods may be omitted so as to not obscure the description of the illustrative embodiments. Such methods and apparati are clearly within the scope of the present teachings.

Generally, it is understood that the drawings and the various elements depicted therein are not drawn to scale. Further, relative terms, such as “above,” “below,” “top,” “bottom,” “upper” and “lower” are used to describe the various elements’ relationships to one another, as illustrated in the accompanying drawings. It is understood that these relative terms are intended to encompass different orientations of the device and/or elements in addition to the orientation depicted in the drawings. For example, if the device were inverted with respect to the view in the drawings, an element described as “above” another element, for example, would now be below that element.

Certain aspects of the present teachings are relevant to components of FBAR devices, FBAR-based filters, their materials and their methods of fabrication. Many details of FBARs, materials thereof and their methods of fabrication may be found in one or more of the following U.S. Patents and Patent Applications: U.S. Pat. No. 6,107,721, to Lakin; U.S. Pat. Nos. 5,587,620, 5,873,153 and 6,507,983 to Ruby, et al.; U.S. patent application Ser. No. 11/443,954, entitled “Piezoelectric Resonator Structures and Electrical Filters” to Richard C. Ruby, et al.; U.S. patent application Ser. No. 10/990,201, entitled “Thin Film Bulk Acoustic Resonator with Mass Loaded Perimeter” to Hongjun Feng, et al.; and U.S. patent application Ser. No. 11/713,726, entitled “Piezoelectric Resonator Structures and Electrical Filters having Frame Elements” to Jamneala, et al.; and U.S. patent application Ser. No. 11/159,753, entitled “Acoustic Resonator Performance Enhancement Using Alternating Frame Structure” to Richard C. Ruby, et al. The disclosures of these patents and patent applications are specifically incorporated herein by reference. It is emphasized that the components, materials and method of fabrication described in these patents and patent applications are representative and other methods of fabrication and materials within the purview of one of ordinary skill in the art are contemplated.

Generally, the present teachings relate to a method of fabricating a piezoelectric layer comprising a selected C-axis orientation (i.e., polarity). In certain embodiments a piezoelectric material fabricated according to representative embodiments comprises a C_N polarity (also referred to as type-C_N piezoelectric material), whereas another piezoelectric material fabricated over the same substrate comprises a C_P polarity (also referred to as type-C_P piezoelectric material). In other embodiments, more than two or more piezoelectric layers are fabricated according to representative embodiments comprise C_N polarity. Furthermore, in representative embodiments the piezoelectric material comprises

AlN. It is emphasized that this is merely illustrative, and that the fabrication of other types of piezoelectric materials is contemplated, including but not limited to the fabrication of zinc oxide (ZnO) and lead zirconium titanate (PZT).

Applications of the illustrative methods will be appreciated by one having ordinary skill in the art. Some of these applications include FBARs useful in transformer applications and FBARs useful in filter applications. For example, the method of fabrication piezoelectric materials comprising antiparallel C-axes (e.g., C_N polarity and C_P polarity) may be useful on the fabrication of film acoustic transformers, such as described in commonly owned U.S. Pat. Nos. 6,987,433 and 7,091,649, to Larson, III, et al. Moreover, the method of fabrication piezoelectric materials comprising antiparallel C-axes (e.g., C_N polarity and C_P polarity) or parallel C-axes (e.g., both C_N polarity) may be useful in the fabrication of the stacked thin film bulk acoustic resonators (SBARs). SBARs comprise stacking two or more layers of piezoelectric material with electrodes between the piezoelectric layers and on the top and bottom of the stack. Such SBARs are described, for example in commonly owned U.S. Pat. Nos. 5,587,620 and 6,060,818, to Ruby, et al. Furthermore, the method of fabricating piezoelectric materials comprising antiparallel C-axes (e.g., C_N polarity and C_P polarity) or both comprising C_N polarity may be useful in CRF applications, such as described in commonly-owned U.S. patent application Ser. No. 12/201,641 entitled "Single Cavity Acoustic Resonators and Electrical Filters Comprising Single Cavity Acoustic Resonators" filed on Aug. 29, 2008 to Bradley, et al.; and in commonly owned U.S. Pat. No. 7,515,018 to Handtmann, et al. The disclosures of U.S. Pat. Nos. 5,587,620; 6,060,818; 6,987,433; 7,091,649; and 7,515,018 and the disclosure of U.S. patent application Ser. No. 12/201,641 are specifically incorporated herein by reference. It is emphasized that the noted applications are intended merely to illustrate applications of the methods of the present teachings, and that the application of the methods of fabricating piezoelectric materials of the present teachings are not limited to these illustrative applications.

FIG. **1**A shows a simplified cross-sectional view of an FBAR **100** in accordance with a representative embodiment. An acoustic stack **102** is provided over a substrate **101** and comprises a first electrode **103** disposed over the substrate **101**; a piezoelectric layer **104** disposed over the first electrode **103**; and a second electrode **105** disposed over the piezoelectric layer **104**. The piezoelectric layer **104** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). The substrate **101** illustratively comprises single-crystal silicon (Si).

A cavity **106** is formed in the substrate **101** beneath the first electrode **103** by a known method. The first electrode **103** and the second electrode **105** may be one of a variety of conductive materials, such as metals suitable as electrodes in BAW applications. Generally, materials suitable for the first electrode **103** and the second electrode **105** comprise Refractory metals. Transition metals or Noble Metals. In specific embodiments, the first and second electrodes **103**, **105** illustratively comprise one or more of molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), ruthenium (Ru), niobium (Nb), hafnium (Hf) and uranium-238 (U-238), or other low-loss metals, and are fabricated using a known method. The piezoelectric layer **104** is fabricated in accordance with the present teachings.

In a representative embodiment, the FBAR **100** comprises a seed layer **108** disposed over an upper surface **107** of the first electrode **103**. As described more fully below, the seed layer **108** is illustratively Al and fosters growth of piezoelectric layer **104** of type-C_N AlN. In a representative embodiment, the seed layer **108** has a thickness in the range of approximately 50 Å to approximately 1000 Å over the upper surface **107**. In other representative embodiments described below, the seed layer **108** is not provided over the first electrode **103**. Rather, the type-C_N piezoelectric layer **104** is formed over the upper surface **107** of the first electrode **103** by methods of representative embodiments.

FIG. **1**B shows a simplified cross-sectional view of an FBAR **109** in accordance with another representative embodiment. The acoustic stack **102** is provided over the substrate **101** and comprises the first electrode **103** disposed over the substrate **101**; the piezoelectric layer **104** disposed over the first electrode **103**; and the second electrode **105** disposed over the piezoelectric layer **104**. The substrate **101** illustratively comprises single-crystal silicon (Si), and comprises an acoustic isolator **110** formed therein and disposed beneath the first electrode **103**. The acoustic isolator **110** may be a known acoustic mirror comprising layers of alternating high acoustic impedance material and low impedance material. The piezoelectric layer **104** illustratively comprises AlN, and is a type-C_N material fabricated in accordance with the present teachings.

In a representative embodiment, the FBAR **109** comprises the seed layer **108** disposed over an upper surface **107** of the first electrode **103**. The seed layer **108** has a thickness in the range of approximately 50 Å to approximately 1000 Å over the upper surface **107**. In other representative embodiments described below, the seed layer **108** is not provided over the first electrode **103**. Rather, the type-C_N piezoelectric layer **104** is formed over the upper surface **107** of the first electrode **103** by methods of representative embodiments.

FIG. **2**A shows a simplified cross-sectional view of an FBAR **200** in accordance with a representative embodiment. The acoustic stack **102** is provided over the substrate **101** and comprises the first electrode **103** disposed over the substrate **101**; the piezoelectric layer **104** disposed over the first electrode **103**; and the second electrode **105** disposed over the piezoelectric layer **104**. The piezoelectric layer **104** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). The substrate **101** illustratively comprises single-crystal silicon (Si).

The cavity **106** is formed in the substrate **101** beneath the first electrode **103** by a known method. The first electrode **103** and the second electrode **105** may be one of a variety of conductive materials as noted above, and are fabricated using a known method. The piezoelectric layer **104** is fabricated in accordance with the present teachings.

In a representative embodiment, and unlike the FBAR **100**, FBAR **200** does not comprise the seed layer **108** over the upper surface **107** of the first electrode **103**. Rather, the type-C_N piezoelectric layer **104** is formed over the upper surface **107** of the first electrode **103** by methods of representative embodiments described below.

FIG. **2**B shows a simplified cross-sectional view of an FBAR **201** in accordance with a representative embodiment. The acoustic stack **102** is provided over the substrate **101** and comprises the first electrode **103** disposed over the substrate **101**; the piezoelectric layer **104** disposed over the first electrode **103**; and the second electrode **105** disposed over the piezoelectric layer **104**. The substrate **101** illustratively comprises single-crystal silicon (Si), and comprises the acoustic isolator **110** formed therein and disposed beneath the first electrode **103**. The acoustic isolator **110** may be a known acoustic mirror comprising layers of alternating high acoustic impedance material and low impedance material. The first electrode **103** and the second electrode **105** may be one of a variety of conductive materials as noted above, and are fabricated using a known method. The piezoelectric layer **104** is fabricated in accordance with the present teachings.

In a representative embodiment, and unlike FBAR **109** shown in FIG. **1**B, the FBAR **201** does not comprise the seed layer **108** over the first electrode **103**. Rather, the type-C_N piezoelectric layer **104** is formed over the upper surface **107** of the first electrode **103** by methods of representative embodiments described below.

FIG. **3**A shows a simplified cross-sectional view of a BAW resonator **300** in accordance with a representative embodiment. The BAW resonator **300** comprises a single cavity such as described in commonly-owned U.S. patent application Ser. No. 12/201,641 to Bradley, et al. The BAW resonator **300** comprises a first electrode **303** disposed over a substrate **301**; a first piezoelectric layer **304** disposed over the first electrode **303**; and a second electrode **305** disposed over the first piezoelectric layer **304**. In the representative embodiment, the first piezoelectric layer **304** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). The substrate **301** illustratively comprises single-crystal silicon (Si).

A second piezoelectric layer **311** is disposed over the second electrode **305**; and a third electrode **312** is disposed over the second piezoelectric layer **311**. The second piezoelectric layer **311** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). A cavity **306** is formed in the substrate **301** beneath the first electrode **303** by a known method. The cavity **306** provides acoustic isolation as described above. Alternatively, an acoustic isolator (not shown in FIG. **3**A) such as described above and comprising alternating layers of comparatively high and low acoustic impedance may be used instead of the cavity **306**.

The first electrode **303**, the second electrode **305** and the third electrode **312** may be one of a variety of conductive materials, such as metals suitable as electrodes in BAW applications. Generally, materials suitable for the first electrode **103** and the second electrode **105** comprise Refractory metals, Transition metals or Noble Metals. In specific embodiments, the first and second electrodes **103**, **105** illustratively comprise one or more of molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), ruthenium (Ru), niobium (Nb), hafnium (Hf) and uranium-238 (U-238), or other low-loss metals, and are fabricated using a known method. The piezoelectric layer **104** is fabricated in accordance with the present teachings.

In a representative embodiment, the FBAR **300** comprises a first seed layer **308** disposed over an upper surface **307** of the first electrode **303**; and a second seed layer **310** disposed over an upper surface **309** of the second electrode **305**. As described more fully below, the first and second seed layers **308**, **310** are illustratively Al and foster growth of the first and second piezoelectric layers **304**, **311** both of type-C_N AlN. In a representative embodiment, the first and second seed layers **308**, **310** each have a thickness in the range of approximately 50 Å to approximately 1000 Å.

It is appreciated that the FBAR **300** of the representative embodiment comprises an acoustic stack comprising more than one type C_N piezoelectric layer. It is emphasized that other BAW resonator structures comprising an acoustic stack comprising more than one type C_N piezoelectric layer are contemplated. For example, decoupled stacked acoustic resonators comprising more than one FBAR with an acoustic decoupler disposed therebetween are contemplated. In such an embodiment, each of the FBARs would include a type C_N piezoelectric layer fabricated in accordance with the present teachings. The present teachings contemplate forming the piezoelectric layers with C_N axes by providing a seed layer over a surface of respective electrodes and forming the respective piezoelectric layer thereover.

Furthermore, in certain BAW structures comprising an acoustic resonator comprising more than one piezoelectric layer, it is desirable to provide piezoelectric layers comprising anti-parallel C-axes (e.g., one type C_N piezoelectric layer, and one type C_P piezoelectric layer). The present teachings also contemplate forming the piezoelectric layers with C_N axes by providing a seed layer over the surface of an electrode, forming the type C_N piezoelectric layer over the seed layer and forming a type C_P piezoelectric layer over another electrode. The type C_P piezoelectric layer is formed using a known method.

FIG. **3**B shows a simplified cross-sectional view of a BAW resonator **302** in accordance with a representative embodiment. The BAW resonator **302** comprises a single cavity such as described in commonly-owned U.S. patent application Ser. No. 12/201,641 to Bradley, et al. The BAW resonator **302** comprises first electrode **303** disposed over substrate **301**; first piezoelectric layer **304** disposed over the first electrode **303**; and second electrode **305** disposed over the first piezoelectric layer **304**. In a representative embodiment, the first piezoelectric layer **304** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). The substrate **301** illustratively comprises single-crystal silicon (Si).

The second piezoelectric layer **311** is disposed over the second electrode **305**; and the third electrode **312** is disposed over the second piezoelectric layer **311**. The second piezoelectric layer **311** is a type-C_N piezoelectric material, and is illustratively type-C_N aluminum nitride (AlN). Cavity **306** is formed in the substrate **301** beneath the first electrode **303** by a known method. The cavity **306** provides acoustic isolation as described above. Alternatively, an acoustic isolator (not shown in FIG. **3**B) such as described above and comprising alternating layers of comparatively high and low acoustic impedance may be used instead of the cavity **306**.

The first electrode **303**, the second electrode **305** and the third electrode **312** may be one of a variety of conductive materials, such as metals suitable as electrodes in BAW applications. Generally, materials suitable for the first electrode **103** and the second electrode **105** comprise Refractory metals, Transition metals or Noble Metals. In specific embodiments, the first and second electrodes **103**, **105** illustratively comprise one or more of molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), ruthenium (Ru), niobium (Nb), hafnium (Hf) and uranium-238 (U-238), or other low-loss metals, and are fabricated using a known method. The piezoelectric layer **104** is fabricated in accordance with the present teachings.

In a representative embodiment, and unlike FBAR **300** shown in FIG. **3**A, the FBAR **302** does not comprise either the first seed layer **308** over an upper surface **307** of the first electrode **303**, or the second seed layer **310** disposed over an upper surface **309** of the second electrode **305**. Rather, (the type-C_N) first and second piezoelectric layers **304**, **311** are formed over upper surface **307** and **309** of the first electrode **303** and the second electrode **305**, respectively, by methods of representative embodiments described below.

It is appreciated that the FBAR **302** of the representative embodiment comprises an acoustic stack comprising more than one piezoelectric layer having a C_N axis. It is emphasized that other BAW resonator structures comprising an acoustic stack comprising more than one type C_N piezoelectric layer are contemplated. For example, decoupled stacked acoustic resonators comprising more than one FBAR with an acoustic decoupler disposed therebetween are contemplated. In such an embodiment, each of the FBARs would include a type C_N piezoelectric layer fabricated in accordance with the present teachings. The present teachings contemplate forming the type C_N piezoelectric layers over a surface of respective electrodes. Furthermore, in certain BAW structures comprising an acoustic resonator comprising more than one piezoelectric layer, it is desirable to provide piezoelectric layers comprising anti-parallel C-axes (e.g., one type C_N piezoelectric layer, and one type C_P piezoelectric layer). The present teachings also contemplate forming the piezoelectric layers with C_N axes and forming a type C_P piezoelectric layer over another electrode. The type C_P piezoelectric layer is formed using a known method.

FIG. **4** shows a simplified schematic diagram of a deposition system **400** in accordance with a representative embodiment. The deposition system **400** comprises components commercially available from Advanced Modular Systems, Inc. of Santa Barbara, Calif. USA, for example. In representative embodiments, the deposition system **400** is a sputter deposition system, many of the components and dynamics of which are known to one of ordinary skill in the art. Because many details of the deposition system **400** and sputtering techniques are known, many details are not provided to avoid obscuring the description of the representative embodiments.

The deposition system **400** comprises a reaction chamber **401**, which is maintained substantially at vacuum during fabrication of piezoelectric materials of the representative embodiments. The deposition system **400** also comprises gas inlets **403**, **404**, **405** as inputs to a flow control system **402**, which controls the flow of selected gases provided to the gas inlets **403**, **404**, **405** and the flow rates of the gases provided. A load and lock chamber **413** is provided to allow for the loading of wafers and transfer them to a reaction chamber **401** without breaking vacuum. The flow control system **402** comprises valves (not shown) for selecting the gases to be flowed into the reaction chamber **401**, flow controllers (not shown) to measure and control the flow rates thereof, and a controller (not shown) comprising suitable software for controlling the valves. Moreover, the deposition system **400** may comprise an exhaust outlet **412**, which has a constant pumping speed, and control of the total pressure in the reaction chamber **401** is provided by changing of gas flow by each flow controller independently or together.

The flow control system **402** may comprise an interface (not shown), such as a graphic user interface (not shown). The deposition system **400** also comprises gas outlets **406**, **407**, **408**, from the flow control system **402**. Gas from the gas outlets **406**, **407**,**408** is provided to the reaction chamber **401**. Notably, the use of mixed gases (e.g., Ar and H_2) from a single source is also contemplated. As described more fully below, these gases form atmospheres used in cleaning and sputter depositing materials **411** from first target **409** and second target **410** over the substrate **101** according to representative embodiments.

As described in connection with representative embodiments below, the gas inlets **403**, **404**, **405** may selectively provide argon (Ar), nitrogen (N) or hydrogen (H), respectively, or a combination thereof. The gas outlets **406**, **407**,**408** provide a mixture of these gases as to the reaction chamber **401**. For example, in forming an Al seed layer (e.g., seed layer **108**), Ar plasma may be formed by the outlet of Ar gas from one of the gas outlets **406**, **407** in the reaction chamber **401**, and results in sputter deposition of seed layer **108** of Al from first and second Al targets **409**, **410** over the first electrode **103**. After the forming of the seed layer **108**, the growth of type-C_N piezoelectric layer (e.g., piezoelectric layer **104**) is provided by selectively sputtering the first and second targets **409**,**410** (e.g., Al) in an Ar/N_2 atmosphere, from gas outlets **406**, **407**.

In another exemplary method where no seed layer is provided, hydrogen (H_2) is provided from one of the gas outlets **406**, **407** to provide a hydrogen atmosphere useful in removing contaminants on the upper surface **107**. The contaminants could include metal oxides, gases such as H_2O, N_2 or O_2 on the upper surface **107**, as well as processing residues such as photoresist. After the cleaning step in the hydrogen atmosphere, the growth of type-C_N piezoelectric layer (e.g., piezoelectric layer **104**) is provided by selectively sputtering the first and second targets **409**, **410** (e.g., Al) in an Ar/N_2/H_2 atmosphere, from gas outlets **406**, **407408** or by pre-mixed source of Ar/H2, and a nitrogen source.

Turning to FIG. **5**, a method **500** of fabricating a piezoelectric layer in accordance with a representative embodiment is shown in a simplified flow-chart. The method **500** is described with direct reference to the components of FIGS. **1**A, **1**B and the deposition system **400** of FIG. **4** for illustrative purposes. Fabrication of other FBAR structures, such as FBAR **300**, using the method **500**, is also contemplated. As will become clearer as the present description continues, the method **500** provides a seed layer **108** over the first electrode **103** in the formation of type-C_N piezoelectric layer **104**. As alluded to above, the method **500** may be used to provide first seed layer **308** over the first electrode **303** and the second seed layer **310** over the second electrode **305** of the BAW resonator **300** by repeating the process after forming the intervening layer(s) of the BAW resonator **300**.

At **501**, the method comprises forming a first electrode over a substrate. Illustratively, the first electrode **103** is formed over the substrate **101**. For purposes of description of the method **500**, the first electrode **103** is formed by sputter-depositing the selected conductive material over the substrate **101** by a known method, although other methods of forming the first electrode are contemplated. Notably, the formation of the cavity **106** in the substrate **101** may be carried out before fabrication of the acoustic stack **102** of the FBAR **100**, with the cavity **106** filled with a sacrificial material (not shown) such as phosphosilicate glass (PSG) or other release processes such as polysilicon and xenon difluoride etchant, known to one of ordinary skill in the art, during the fabrication of layers of the acoustic stack **102**; and released after the forming of the layers of the acoustic stack **102**. Alternatively, the acoustic isolator **110** is formed in the substrate **101** before forming of the first electrode **103** of the FBAR **109**.

The fabrication of the piezoelectric layer **104** begins with cleaning the upper surface **107** of the first electrode **103** before the forming of the piezoelectric layer **104**. In a representative embodiment, this cleaning step comprises flowing only Ar to one of the gas inlets **403**, **404**,**405** and to one of the gas outlets **406**, **407** to provide an Ar atmosphere in the reaction chamber **401**. An RF bias is applied to the first electrode **103** and the reaction chamber **401** is maintained at ground, so that the first electrode **103** functions as a cathode. An Ar plasma is formed in the reaction chamber **401** and bombards the upper surface **107** of the first electrode **103**. Illustratively, the RF power is provided in the range of approximately 15 W to approximately 1 kW, and the Ar bombardment of the upper surface **107** of the first electrode is maintained for a few seconds to a few minutes to ensure proper removal of contaminants. Notably, during this cleaning step, no voltage is applied to the first and second targets **409**, **410**.

It is believed that the comparatively high kinetic energy of the Ar ions provides suitable bombardment of the upper surface **107** to remove substantially therefrom contaminants such as adsorbed water, adsorbed oxide, adsorbed nitrides and native oxides formed on materials commonly used in the fabrication of the first electrode **103**. By substantially removing contaminants from the upper surface **107**, the formation of a comparatively pure and electropositive Al seed layer **108** is fostered. Thereafter, a type-C_N AlN piezoelectric layer may be formed by deposition of AlN over the seed layer **108** as described above. Furthermore, in an embodiment where the first electrode **103** comprises Pt, by this cleaning step in the Ar atmosphere, it is believed that contaminants such as adsorbed water, adsorbed oxides and adsorbed nitrides are believed to be removed from the Pt, which does not readily form native oxides.

At **502**, the method **500** comprises forming the seed layer **108** over the upper surface **107** of the first electrode **103**. In a representative embodiment, at this point the RF power to the first electrode **103** is terminated, and AC power is provided between the first target **409** and the second target **410** in the reaction chamber **401**. In a representative embodiment, the piezoelectric material comprises two components, and the first and second targets **409**, **410** comprise one of the components. Illustratively, AlN is the piezoelectric material, and the first and second targets **409**,**410** comprise Al. Aluminum is sputtered from the first and second targets **409**,**410** during the negative potential half-cycle of AC power applied to the first and second targets **409**,**410** and provides seed layer **108** over the upper surface **107** of the first electrode **103**. During the forming of the seed layer **108**, Ar is flowed to one of the gas inlets **403**, **404**, **405** and from one of the gas outlets **406**, **407**; and no other gases are flowed from the other gas outlet **406**, **407**. As a result, Ar plasma created in the reaction chamber **401** results in the sputter deposition of a substantially pure aluminum seed layer from the first and second targets **409**, **410** and over the upper surface **107** of the first electrode **103**. Notably, the longer AC power is applied between the first and second targets **409**,**410**, the thicker the seed layer **108** that is formed.

At **503**, and after the seed layer **108** is formed, the method **500** comprises flowing a first component of the piezoelectric layer and sputtering the piezoelectric layer **104** over the substrate **101**. In a representative embodiment used to form AlN, the first component comprises nitrogen (N_2) gas. The flowing of nitrogen into the reaction chamber **401** comprises providing nitrogen to one of the gas inlets **403**, **404**, **405** and from one of the gas outlets **406**, **407**, **408**, while continuing the flow of Ar to another of the gas inlets **403**, **404**, **405** and from the other of the gas outlets **406**, **407**, **408**. During the flowing of nitrogen, AC power is supplied between the first and second targets **409**,**410**, which comprise the second component (e.g., Al) of the piezoelectric material (e.g., AlN), and the piezoelectric material is formed over the surface of the first and second targets **409**,**410**. In a representative embodiment, the AC power has a frequency in the range of approximately 20 kHz to approximately 100 kHz, and power in the range of approximately 4 kW to approximately 7 kW. Illustratively, the AC power has a frequency of 7 kW and a frequency of 40 kHz.

The Ar/N_2 plasma is maintained, and sputters the AlN from the first and second targets **409**,**410** to the seed layer **108**, in a preferred orientation to provide type C_N AlN over the seed layer **108**. Beneficially, the depositing of the piezoelectric layer **104** in the portion of the method is effected without breaking vacuum conditions in the system **400**, and comparatively rapidly after completion of the forming of the seed layer **108**. Maintaining vacuum and relatively rapidly beginning the deposition of the piezoelectric layer **104** is believed to substantially prevent adsorption of oxides and nitrides or the formation of other contaminants over the exposed surface (s) of the seed layer **108**.

It is believed that because the Al seed layer **108** is comparatively free from contaminants due to the cleaning step in Ar, a substantially electropositive surface of Al is formed over the upper surface **107** of the first electrode **103**. The Al seed layer **108** is comparatively highly reactive, and attracts nitrogen of the sputtered AlN. As such, it is believed that AlN is oriented with the nitrogen bonded to the electropositive seed layer of aluminum, and the aluminum of the AlN not being bonded is exposed (i.e., in a structure: seed layer-NAl). Sputtered AlN is then bonded to the exposed aluminum, with the nitrogen bonded to the exposed aluminum (i.e., in a structure: seed layer-N-AL-N-AL). This sequence results in the forming of the crystal structure of type-C_N AlN piezoelectric material, and continues until a suitable thickness of the type-C_N AlN (e.g., piezoelectric layer **104**) is realized. In one embodiment, the AlN layer has a thickness of approximately 12,000 Å.

The flow rates of Ar and N_2 are set to control the stress of the resultant AlN. Notably, a higher flow rate of Ar results in tensile stress in the AlN; a lower the flow rate of Ar results in compressive stress in the AlN. Similarly, a higher the flow rate of N_2 results in tensile stress in the AlN; and a lower flow rate of N_2 results in compressive stress in the AlN. In representative embodiments, the flow rate of Ar is in the range of approximately 6 sccm to approximately 25 sccm, and the flow rate of N_2 is in the range of approximately 39 sccm to approximately 50 sccm.

After the piezoelectric layer **104** is formed, the second electrode **105** is formed over the piezoelectric layer **104**. The second electrode **105** comprises a metal that is sputter-deposited over the piezoelectric layer **104** by a known method. Illustratively, the second electrode **105** comprises the same material as the first electrode **103**. Notably, different materials may be used for the electrodes as may be beneficial to the FBAR (BAW resonator) **100**.

After the forming of the second electrode **105**, the release of the sacrificial material to form the cavity **106** is carried out using a suitable etchant such as HF. As should be appreciated, if unprotected the seed layer **108** may be etched by the etchant as well. In order to prevent this from significantly deteriorating the seed layer **108**, a protective layer (not shown) over and/or around the acoustic stack **102** comprising the first electrode **103**, the seed layer **108**, the piezoelectric layer **104** and the second electrode **105**. The protective layer may comprise a metal 'dam' formed from the same metal as the first and second electrodes **103**, **105**, for example; or may be formed of a material impervious to the etchant (e.g., HF). Such protective layers are formed by known deposition, lithography and etching sequences. Alternatively, a comparatively thin (e.g., 50 Å) seed layer **108** may be provided. It is believed that a comparatively thin seed layer will not be appreciably etched by the etchant used to release the sacrificial material from the cavity **106**. Of course, if instead of the cavity **106**, the acoustic isolator **110** is implemented as in FBAR **109**, the release of sacrificial material and thus the passivation material would not be necessary.

The FBARs **100**, **109** described in connection with the method **500** comprise a single piezoelectric layer. As noted above, the acoustic stack of certain resonator structures comprises more than one piezoelectric layer. It is emphasized that the method **500** can be repeated to form a second type-C_N AlN piezoelectric layer. For example, by repeating the method **500**, BAW resonator **300** comprising first and second piezoelectric layers **304**, **311** is fabricated by forming first and second seed layers **308**, **310** respectively over respective upper surfaces **307**,**309** of first and second electrodes **303**, **305**.

In certain applications, two or more piezoelectric layers may be included in the acoustic stack, and have opposing C-axes. For example, in an acoustic stack described U.S. Pat. No. 7,515,018, the C-axes of the piezoelectric layers may be antiparallel. As can be appreciated, in a structure comprising two piezoelectric layers in an acoustic stack, the first piezoelectric may be type-C_N piezoelectric material (e.g., first piezoelectric layer **304**), and the second piezoelectric layer **311** may be type-C_P piezoelectric material. In such an embodiment, the deposition system **400** and method **500** could be used to form the type-C_N piezoelectric layer by method **500**, and the type-C_P piezoelectric layer would be formed by a known method using deposition system **400**. For example, the first electrode **103** may be formed as described in **501** above; and the C_P piezoelectric layer may be formed by flowing the first component of the piezoelectric material as described in **503** above. Notably, in forming a C_P piezoelectric layer, the sequence of **502** is not performed.

FIG. **6** shows a flow-chart of a method **600** of fabricating a piezoelectric layer in accordance with a representative embodiment. Many of the details of the method **600** are common to the method **500**, and may not be repeated in order to avoid obscuring the presently described embodiments.

The method **600** is described with direct reference to the components of FIGS. **2**A, **2**B and the deposition system **400** of FIG. **4** for illustrative purposes. Fabrication of other FBAR structures, such as FBAR **302**, using the method **600**, is also contemplated. As will become clearer as the present description continues, the method **600** may be used to form type-C_N piezoelectric layer **104** over the upper surface **107** of the first electrode **103**. As alluded to above, the method **600** may be used to provide the first piezoelectric layer **304** over the upper surface **307** of the first electrode **303** and the second piezoelectric layer **311** over the upper surface **309** of the second electrode **305** of the BAW resonator **302** by repeating the process after forming the intervening layer(s) of the BAW resonator **302**.

At **601** the method comprises providing a substrate. Illustratively, the substrate formed in **601** comprises first electrode **103**, which is formed over the substrate **101**. For purposes of description of the method **600**, the first electrode **103** comprises a metal that is sputter-deposited over the substrate **101** by a known method. Notably, the formation of the cavity **106** in the substrate **101** may be carried out before fabrication of the layers of the acoustic stack **102** of FBAR **100**, with the cavity **106** filled with a sacrificial material (not shown) such as phospho-silicate glass (PSG) during the fabrication of layers of the acoustic stack **102**, and released after forming the layers of the acoustic stack **102**. Alternatively, the acoustic isolator **110** is formed in the substrate **101** before forming of the first electrode **103** of FBAR **109**.

At **602**, the fabrication of the piezoelectric layer **104** begins with cleaning an upper surface **107** of the first electrode **103** before the forming of the piezoelectric layer **104**. In a representative embodiment, this cleaning step comprises flowing Ar and H_2 to respective gas inlets **403**, **404**,**405** and from one of the gas outlets **406**, **407**, **408**. An RF bias is applied to the first electrode **103** and the reaction chamber **401** is maintained at ground, so that the first electrode **103** functions as a cathode. As in method **500**, an Ar plasma is formed and bombards the upper surface **107** of the first electrode **103**. Illustratively, the RF power is provided in the range of approximately 15 W to approximately 1 kW, and the Ar bombardment of the upper surface **107** of the first electrode is

maintained for a few seconds to a few minutes to ensure proper removal of contaminants. Notably, during this cleaning step, no voltage is applied to the first and second targets **409**,**410**; and therefore sputtering of material (e.g., Al) from first and second targets **409**,**410** is insignificant. As such, and in contrast to the method **500**, no seed layer (e.g., seed layer **108**) is formed over the upper surface **107** of the first electrode **103**.

The hydrogen plasma formed in the reaction chamber **401** bombards the upper surface **107** of the first electrode **103**. The flow of H_2 in **402** provides ionized hydrogen (e.g., H_2^+ or H^+) in the reaction chamber **401** that provides a reducing agent at the upper surface **107**. The ionized hydrogen is believed to react with many contaminants such as water, adsorbed oxides, nitrides and native oxides that may be present on the upper surface **107**, and fosters their removal to provide a comparatively clean surface. Moreover, it is believed that the ionized hydrogen forms metal hydrides by saturating dangling bonds on the surface of the metal of the first electrode **103**. Furthermore, in an embodiment where the first electrode **103** comprises Pt, by the cleaning step with H_2, it is believed that contaminants such as adsorbed water, oxides and nitrides are believed to be removed on Pt, which does not readily form native oxides. Notably, however, because no electrical potential is applied to the first and second targets **409**,**410** during **602**, Al is not appreciably sputtered from the first and second targets **409**,**410**.

At **603** the method **600** comprises flowing a first component of the piezoelectric layer **104**. In a representative embodiment used to form AlN, the first component comprises nitrogen (N_2) gas. The flowing of nitrogen into the reaction chamber **401** comprises providing nitrogen to one of the gas inlets **403**, **404**, **405** and from one of the gas outlets **406**, **407**, **408**, while continuing the flow of Ar to another of the gas inlets **403**, **404**, **405** and from the other of the gas outlets **406**, **407**, **408**.

Notably, H_2 may be provided to the same gas outlet **406**, **407**, **408** that provides Ar; or a separate outlet (not shown) may be provided into the reaction chamber to provide an Ar/N/H atmosphere. Alternatively, after the completion of **602**, hydrogen flow may be terminated. The flow rates of Ar and N_2 are set to control the stress of the resultant AlN. As described previously, a higher the flow rate of Ar results in tensile stress in the AlN; and a lower the flow rate of Ar results in compressive stress in the AlN. Similarly, a higher the flow rate of N_2 results in tensile stress in the AlN; and a lower the flow rate of N_2 results in compressive stress in the AlN. In representative embodiments, the flow rate of Ar is in the range of approximately 6 sccm to approximately 25 sccm, and the flow rate of N_2 is in the range of approximately 39 sccm to approximately 50 sccm.

During the flowing of nitrogen, AC power is supplied between the first and second targets **409**,**410**, and AlN—H compounds are formed over the surface of the first and second targets **409**,**410**. Moreover, NH_x compounds are believed to be formed in the reaction chamber **401**. It is believed that NH_x compounds formed in the reaction chamber **401** fosters the formation of form an AlN—H compound, due to reactions on the surface of the first and second targets **409**,**410** between Al and NHx.

The greater the frequency of the AC power, the lower the deposition rate of AlN. Accordingly, the frequency of the AC power generally should not exceed 100 kHz. Notably, if the flow of hydrogen is maintained during **603**, the cleaning action of hydrogen is realized, but due to its comparatively small atomic mass, hydrogen does not appreciably sputter Al—N from the first and second targets **409**,**410**.

At **604** piezoelectric material is sputtered from the first and second targets **409**,**410** over the substrate **101**. In a specific embodiment, AlN—H formed on the first and second targets **409**,**410** is sputtered to the upper surface **107** of the first electrode **103**. The metal hydrides formed at the upper surface **107** are believed to present an electronegative surface that attracts the aluminum of the AlN—H sputtered from the target. Accordingly, the desired orientation (i.e., metal hydride-AlN—AlN—AlN) to form the crystal structure of type-C_N AlN piezoelectric material is provided and **603** continues until a suitable thickness of the type-C_N AlN (e.g., piezoelectric layer **104**) is realized. In one embodiment, the AlN layer has a thickness of approximately 12,000 Å.

It is believed that hydrogen gas molecules (H_2) and atoms (H) attach to the AlN on the surface of the metal of the first electrode **103**. The hydrogen atoms then penetrate into the interior next to Al side of AlN molecule to form an aluminum-hydride-nitride substance. The AlN molecules are stretched apart to accommodate the hydrogen atoms. The physical structure of the H—AlN molecule may also change. Then as a result of adsorption, the hydrided part of H—AlN aligns and migrates to the surface of the metal hydride formed on the first electrode **103**, combines into hydrogen molecules H_2 and pulls the Al part of AlN toward to first electrode **103**.

As noted above, the H_2 flow into the reaction chamber **401** may be continuous during the forming of the piezoelectric material. As described above, it is believed that the presence of ionized hydrogen in the reaction chamber provides a reducing agent that can remove contaminants such as oxides, nitrides and water, which can interfere with the forming of type-C_N piezoelectric material, or can reduce the coupling coefficient (kt^2) and therefore degrade the quality (Q) factor of the piezoelectric material, or both. In a representative embodiment, the flow rate of H_2 during the forming of the AlN is at least approximately 8 sccm. In certain embodiments, the flow rate of H_2 during the forming of the AlN is as great as approximately 30 sccm. Illustratively, a flow rate of H_2 of approximately 14 sccm provides a C_N AlN piezoelectric material with kt^2 of approximately 5.5%. As described below, the coupling coefficient kt^2 of AlN fabricated with continuous flow of H_2 at the flow rates noted provides C_N AlN piezoelectric material with kt^2 of approximately 2% to approximately 6.6%. FIG. **7** shows the coupling coefficient versus hydrogen flow rate during the forming of the piezoelectric layer in **603**.

After the piezoelectric layer **104** is formed, the second electrode **105** is formed over the piezoelectric layer **104**. The second electrode **105** comprises a metal that is sputter-deposited over the piezoelectric layer **104** by a known method. Illustratively, the second electrode **105** comprises the same material as the first electrode **103**.

The FBARs **200**, **201** described in connection with the method **600** comprise a single piezoelectric layer. As noted above, the acoustic stack of certain resonator structures comprises more than one piezoelectric layer. It is emphasized that the method **600** may be repeated to form a second type-C_N AlN piezoelectric layer. For example, by repeating the method **600** in a selected sequence, BAW resonator **302** comprising first and second piezoelectric layers **304**, **311**, respectively, are formed over respective upper surfaces **307**, **309** of first and second electrodes **303**, **305**.

In certain applications, two or more piezoelectric layers may be included in the acoustic stack, and have opposing C-axes. For example, in an acoustic stack described in U.S. Pat. No. 7,515,018, the C-axes of the piezoelectric layers may be antiparallel. As can be appreciated, in a structure comprising two piezoelectric layers in an acoustic stack, the first piezoelectric may be type-C_N piezoelectric (e.g., first and second piezoelectric layer **304**), and the second piezoelectric layer **311** may be type-C_P piezoelectric. In such an embodiment, the deposition system **400** would be used to form the type-C_N piezoelectric layer by method **600**, and the type-C_P piezoelectric layer would be formed by a known method using deposition system **400**.

If the second piezoelectric layer (e.g., second piezoelectric layer **311**) is type-C_N AlN, the cleaning step of method **600** would be carried out to remove contaminants from the electrode over which the second piezoelectric layer is formed (e.g., second electrode **305**). If there is no intervening acoustic decoupling layer or intervening electrode, the cleaning step of the method **600** would be carried out to remove contaminants from the surface (e.g., upper surface **309**) of the second electrode **305**. The forming of the second piezoelectric layer would be effected by repeating **603** of the method **600**.

In certain applications, two or more piezoelectric layers may be included in the acoustic stack, and have opposing C-axes. For example, in the acoustic stacks described in U.S. patent application Ser. No. 12/201,641 and U.S. Pat. No. 7,515,018, the C-axes of the piezoelectric layers may be antiparallel. As can be appreciated, in a structure comprising two piezoelectric layers in an acoustic stack, the first piezoelectric may be type-C_N (e.g., first piezoelectric layer **304**), and the second piezoelectric layer (e.g., second piezoelectric layer **311**) may be type-C_P. In such an embodiment, the deposition system **400** would be used to form the type-C_N piezoelectric layer by method **600**, and the type-C_P piezoelectric layer would be formed by a known method using deposition system **400**.

FIG. **7** shows a graph of intrinsic coupling constant (kt^2) versus Hydrogen flow rate of a piezoelectric layer fabricated in accordance with a representative embodiment. In particular, in region **701** of the graph, the intrinsic coupling constant, kt^2 is indicative of indicative of C_P AlN formed in accordance with a representative embodiment. By contrast, in region **702**, the intrinsic coupling constant, kt^2 is indicative of C_N AlN formed by a known method.

In accordance with illustrative embodiments, methods of fabricating piezoelectric materials and acoustic resonators for various applications such as in electrical filters are described. One of ordinary skill in the art appreciates that many variations that are in accordance with the present teachings are possible and remain within the scope of the appended claims. These and other variations would become clear to one of ordinary skill in the art after inspection of the specification, drawings and claims herein. The invention therefore is not to be restricted except within the spirit and scope of the appended claims.

The invention claimed is:

1. A method of fabricating a piezoelectric material comprising a first component and a second component, the method comprising:
  - providing a substrate;
  - initially flowing hydrogen over the substrate;
  - after the initially flowing of the hydrogen over the substrate,
  - flowing the first component to form the piezoelectric material over a surface of a target comprising the second component;
  - sputtering the piezoelectric material from the target onto the substrate; and
  - flowing the hydrogen over the substrate during the sputtering at a rate sufficient to cause a piezoelectric film having a defined polarity to be formed over the substrate, wherein

a seed layer is not formed over the substrate prior to the sputtering.

2. A method of fabricating a piezoelectric material as claimed in claim 1, wherein the piezoelectric film comprises a compression-negative (C_N) polarity.

3. A method of fabricating a piezoelectric material as claimed in claim 1, wherein the flowing of hydrogen is continuous during the fabricating of the piezoelectric film.

4. A method of fabricating a piezoelectric material as claimed in claim 1, further comprising, after the depositing:

ceasing flow of the hydrogen;

forming a second substrate over the piezoelectric film; and

sputtering the piezoelectric material from the target over the second substrate.

5. A method of fabricating a piezoelectric material as claimed in claim 4, further comprising, before forming the second substrate flowing hydrogen over the second substrate, wherein the piezoelectric material comprises a compression-negative (C_N) material.

6. A method of fabricating a piezoelectric material as claimed in claim 3, wherein the substrates comprise a metal.

7. A method of fabricating a piezoelectric material as claimed in claim 6, wherein the metal comprises one of: molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), and ruthenium (Ru).

8. A method of fabricating a piezoelectric material as claimed in claim 1, wherein the first component comprises nitrogen and the second component comprises aluminum.

9. A method of fabricating a piezoelectric material as claimed in claim 4, wherein the piezoelectric material sputtered on the first substrate comprises a compression-negative (C_N) material, and the piezoelectric material sputtered over the second substrate comprises a compression-positive (C_P) material.

10. A method of fabricating a piezoelectric material as claimed in claim 1, wherein the flowing of hydrogen during the depositing forms NH_x.

11. A method of fabricating a bulk acoustic wave (BAW) resonator having a piezoelectric material consisting essentially of first and second components, the method comprising:

forming a first electrode over a substrate;

forming a seed layer consisting essentially of the second component over the substrate;

flowing the first component of the piezoelectric material to form the piezoelectric material over a surface of a target consisting essentially of the second component of the piezoelectric material; and

sputtering the piezoelectric material from the target onto the seed layer to deposit a piezoelectric layer having a compression-negative (C_N) polarity.

12. A method as of fabricating a BAW resonator as claimed in claim 11, further comprising forming a second electrode over the piezoelectric material.

13. A method as of fabricating a BAW resonator as claimed in claim 11, wherein the seed layer comprises aluminum.

14. A method of fabricating a BAW resonator as claimed in claim 13, wherein the first electrode and the second electrode comprise one of molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), and ruthenium (Ru).

15. A method of fabricating a BAW resonator as claimed in claim 11, further comprising, after the forming of the first electrode and before the forming of the seed layer, forming a plasma and removing a contaminant from a surface of the first electrode.

16. A method of fabricating a BAW resonator as claimed in claim 11, further comprising, after the forming of the seed layer, maintaining a flow of an inert gas over the surface of the seed layer during the depositing of the first component and the piezoelectric material.

17. A method of fabricating a BAW resonator as claimed in claim 12, further comprising, after the depositing of the piezoelectric material: sputtering a second piezoelectric material over the second electrode, wherein the second piezoelectric material comprises a compression-positive (C_P) polarity.

18. A method of fabricating a BAW resonator as claimed in claim 12, wherein the first electrode and the second electrode comprise a metal.

19. A method of fabricating a BAW resonator as claimed in claim 18, wherein the metal comprises one of: molybdenum (Mo), aluminum (Al), tungsten (W), platinum (Pt), and ruthenium (Ru).

20. A method of fabricating a BAW resonator as claimed in claim 11, wherein the first component comprises nitrogen and the second component comprises aluminum.

21. A method of fabricating a BAW resonator as claimed in claim 11, wherein the seed layer is selected to foster growth of the piezoelectric material comprising the compression-negative (C_N) polarity.

22. A method of fabricating a BAW resonator as claimed in claim 11, wherein vacuum is maintained during the method.

23. The method of claim 11, wherein the first component is nitrogen (N) and the second component is aluminum (Al).

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